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RESEARCH MEMORANDUM

for the

Air Materiel Command, U. S. Air Force

STATIC LONGITUDINAL STABILITY OF A TANDEM-COUPLED BOMBER-FIGHTER AIRPLANE CONFIGURATION PROPOSED BY ALL AMERICAN AIRWAYS, INC.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
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SUMMARY

At the request of the Air Materiel Command an investigation was made in the Langley free-flight tunnel to determine the static longitudinal stability and control characteristics of models coupled together in a tandem configuration proposed by All American Airways, Inc. Force tests were made using $\frac{1}{20}$-scale models of B-29 and F-80 airplanes to determine the effects of coupling the fighter to the tail of the bomber.

The results of the investigation showed that for the bomber alone the aerodynamic center was 0.21 mean aerodynamic chord behind the center of gravity (stable) but that for the tandem configuration the aerodynamic center was 0.09 mean aerodynamic chord forward of the center of gravity of the combination (unstable). The elevator effectiveness of the bomber was reduced approximately 50 percent by addition of the fighter. Some recent flight tests made in the free-flight tunnel with models simulating the proposed configuration indicate that the reduction in stability may be minimized by incorporating a hinged coupling permitting freedom in pitch.

INTRODUCTION

At the request of the Air Materiel Command an investigation was made in the Langley free-flight tunnel to determine the static longitudinal stability and control characteristics of models coupled together in a tandem configuration proposed by All American Airways, Inc., for aerial refueling. This configuration consists of a fighter coupled rigidly behind a bomber with the nose of the fighter inserted in a conical receptacle built into the rear section of the bomber fuselage. Force tests were made using $\frac{1}{20}$-scale models of the B-29 and F-80 airplanes to determine the effects of coupling the fighter to the bomber. Because difficulty has been experienced in estimating the downwash correction factors to be used in theoretical calculations of the longitudinal stability for this type of configuration, the downwash factors were computed from the data obtained in the force tests.

SYMBOLS

W	weight, pounds
S	wing area, square feet
$\bar{c}$	wing mean aerodynamic chord, feet
b	wing span, feet
l	tail length, distance from center of gravity to quarter root-chord station of horizontal tail, feet
m	distance from center of gravity of the bomber alone to center of gravity of the bomber-fighter combination, feet
n	distance from center of gravity of the bomber-fighter combination to center of gravity of fighter, feet
V	airspeed, feet per second
ρ	air density, slugs per cubic foot
q	dynamic pressure, pounds per square foot $\left(\frac{\rho}{2}V^2\right)$
α	angle of attack of reference axis, degrees
ϵ	downwash angle, degrees
δ_e	angle of elevator deflection, positive downward, degrees
C_L	lift coefficient (Lift/qS)

C_m pitching-moment coefficient (Pitching moment/$qS\bar{c}$)

C_{L_α} rate of change of lift coefficient with angle of attack, per degree $\left(\partial C_L/\partial\alpha\right)$

C_{m_α} rate of change of pitching-moment coefficient with angle of attack, per degree $\left(\partial C_m/\partial\alpha\right)$

$C_{m_{\delta_e}}$ elevator effectiveness, rate of change of pitching-moment coefficient with elevator deflection, per degree $\left(\partial C_m/\partial\delta_e\right)$

$\frac{d\epsilon}{d\alpha}$ rate of change of downwash angle with angle of attack, per degree

Subscripts

b bomber, B-29

f fighter, F-80

w wing

t horizontal tail

APPARATUS

The investigation was made in the NACA free-flight tunnel which is described in references 1 and 2.

A three-view drawing of the models used in the investigation is shown in figure 1 and the physical characteristics are listed in table I. The weights of the full-scale airplanes were assumed to be 120,000 and 12,000 pounds for the bomber and fighter, respectively. The center of gravity of each model was assumed to be located at 0.26 mean aerodynamic chord and the resulting center of gravity of the combination was at 0.74 mean aerodynamic chord of the bomber. The F-80 model represented approximately a scale model of a prototype of the F-80 airplane.

FORCE TESTS

The lift, drag, and pitching moment of the B-29 model with horizontal tail on and off, of the F-80 model alone, and of the combination were measured through an angle-of-attack range of -2° to 8°. Elevator control effectiveness of the B-29 was measured for both the coupled and uncoupled conditions. Elevator settings of $\pm 5^\circ$ were used. All the coefficients for the coupled condition were based on the wing area and mean aerodynamic chord of the B-29 and the center of gravity of the combination.

CALCULATIONS

The downwash factor for each surface was calculated by comparing the pitching-moment coefficient about the airplane center of gravity produced by the surface while in the downwash field with the pitching-moment coefficient produced by the same surface when isolated from the downwash field.

The downwash factor $\left(1 - \frac{d\epsilon}{d\alpha}\right)_{wb}$ at the tail of the bomber due to the bomber wing was calculated from the force-test data for the bomber alone by the following equation:

$$\left(1 - \frac{d\epsilon}{d\alpha}\right)_{wb} \approx - \frac{C_{m_{\alpha_{tail\ on}}} - C_{m_{\alpha_{tail\ off}}}}{C_{L_{\alpha_{tail}}} \frac{l}{c}\left(\frac{S_{b_t}}{S_{b_w}}\right)} \tag{1}$$

where $C_{m_{\alpha_{tail\ on}}}$ and $C_{m_{\alpha_{tail\ off}}}$ are based on the wing area of the bomber. The term $C_{L_{\alpha_{tail}}}$ is the lift-curve slope for the tail when not in the downwash field of the wing and is based on the tail area.

The total downwash factor $\left(1 - \frac{d\epsilon}{d\alpha}\right)_{wtb}$ due to the bomber wing and tail on the fighter was calculated from the force-test data by the following approximate equation:

$$\left(1 - \frac{d\epsilon}{d\alpha}\right)_{wtb} \approx -\frac{C_{m_{\alpha_{bf}}} - C_{m_{\alpha_b}} - C_{L_{\alpha_b}}\left(\frac{m}{c}\right)}{\frac{S_{f_w}}{S_{b_w}} C_{L_{\alpha_f}}\left(\frac{n}{c}\right)} \tag{2}$$

where $C_{m_{\alpha_{bf}}}$ is based on wing area and mean aerodynamic chord of the bomber and the center of gravity of the combination.

To determine the contribution of the bomber tail to the total downwash factor it was assumed that the downwash due to the bomber wing was the same at the fighter wing as at the bomber tail. Therefore:

$$\left(1 - \frac{d\epsilon}{d\alpha}\right)_{tb} \approx \frac{\left(1 - \frac{d\epsilon}{d\alpha}\right)_{wtb}}{\left(1 - \frac{d\epsilon}{d\alpha}\right)_{wb}} \tag{3}$$

The error in this assumption is believed to be negligible since the distance between the fighter wing and the bomber tail is small and there is probably only a small gradient of $\left(1 - \frac{d\epsilon}{d\alpha}\right)_{wb}$ in that distance.

RESULTS AND DISCUSSION

The data obtained from the force tests are given in figures 2 and 3, and the aerodynamic parameters measured from these data and the calculated downwash factors are listed in table II. Drag and pitching-moment data for the F-80 model were unreliable due to the small size of the model and low tunnel speed and therefore are not presented. The force tests showed that for the bomber alone the aerodynamic center was 0.21 mean aerodynamic chord behind the center of gravity (stable) but that for the tandem configuration the aerodynamic center was 0.09 mean aerodynamic chord forward of the center of gravity of the combination (unstable). This reduction in stability produced by addition of the fighter to the bomber resulted from a 0.48 mean-aerodynamic-chord rearward shift of the center of gravity and a 0.18 mean-aerodynamic-chord rearward shift of the aerodynamic center.

The elevator effectiveness of the bomber was reduced approximately 50 percent by addition of the fighter. This reduction was produced mainly from the action of the elevator in changing the downwash angle, thus altering the effective angle of attack of the fighter and tending to produce a pitching moment opposite to that produced by the deflected elevator of the bomber. The effect of the rearward shift of the center of gravity on the elevator effectiveness was small because the effective tail length was decreased only slightly by this shift.

Some flight tests have recently been conducted in the free-flight tunnel using models simulating the proposed tandem configuration. The results of these tests (unpublished) indicated that for any center-of-gravity location the longitudinal stability was improved by changing from the rigid coupling to one freely hinged in pitch. In fact, for any given center-of-gravity location, the stability of the model with hinged coupling appeared to be about the same as for the bomber alone. On the other hand, with the rigid coupling, longitudinal instability was encountered over a fairly large range of center-of-gravity locations for which the bomber alone was stable. It appears therefore that the reduction in stability produced by the addition of the fighter to the bomber may be minimized by incorporating a hinged coupling permitting freedom in pitch.

CONCLUSIONS

The results of the investigation of the longitudinal stability of the tandem-coupled bomber-fighter airplane configuration proposed by All American Airways, Inc., showed that for the bomber alone the aerodynamic center was 0.21 mean aerodynamic chord behind the center of gravity (stable) but that for the tandem configuration the aerodynamic center was 0.09 mean aerodynamic chord forward of the center of gravity of the combination (unstable). The elevator effectiveness of the bomber was reduced approximately 50 percent by addition of the fighter. Some recent flight tests made in the free-flight tunnel with models simulating the proposed configuration indicate that the reduction in stability may be minimized by incorporating a hinged coupling permitting freedom in pitch.

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1. Shortal, Joseph A., and Osterhout, Clayton J.: Preliminary Stability and Control Tests in the NACA Free-Flight Wind Tunnel and Correlation with Full-Scale Flight Tests. NACA TN 810, 1941.

2. Shortal, Joseph A., and Draper, John W.: Free-Flight-Tunnel Investigation of the Effect of Fuselage Length and the Aspect Ratio and Size of the Vertical Tail on Lateral Stability and Control. NACA ARR 3D17, 1943.

3. Tosti, Louis P.: Low-Speed Static Stability and Damping-in-Roll Characteristics of Some Swept and Unswept Low-Aspect-Ratio Wings. NACA TN 1468, 1947.

TABLE I

PHYSICAL CHARACTERISTICS OF THE $\frac{1}{20}$-SCALE B-29 AND F-80 MODELS

Distance between c.g. of B-29 and F-80 when coupled, ft	3.4
Distance of c.g. of coupled configuration rearward of c.g. of B-29, ft	0.31

	B-29	F-80
Wing area, sq ft	4.35	0.59
Span, ft	7.07	1.95
Mean aerodynamic chord, ft	.64	.34
Center-of-gravity location, percent M.A.C.	26.0	26.0
Gross weight, lb	15.00	1.50
Horizontal-tail length, ft	2.44	0.73
Horizontal-tail area, sq ft	0.83	0.105

TABLE II

AERODYNAMIC PARAMETERS OBTAINED FROM FORCE TESTS OF THE B-29 AND F-80

[A value of $C_{L_{\alpha_t}}$ of 0.072 for the bomber tail was estimated from data of reference 3]

Configuration	C_{L_α}	$C_{m_{\alpha}}$ tail off	$C_{m_{\alpha}}$ tail on	$\frac{dC_m}{dC_L}$	$C_{m_{\delta_e}}$
B-29	0.113	0.010	-0.026	-0.21	-0.022
F-80	.089	-----	------	-----	------
Coupled B-29 and F-80	.121	-----	.010	.09	-.009

CALCULATED DOWNWASH FACTORS

$$\left(1 - \frac{d\epsilon}{d\alpha}\right)_{wb} = 0.69$$ (bomber wing on tail)

$$\left(1 - \frac{d\epsilon}{d\alpha}\right)_{wtb} = 0.32$$ (bomber wing and tail on fighter wing)

$$\left(1 - \frac{d\epsilon}{d\alpha}\right)_{tb} = 0.46$$ (bomber tail on fighter wing)

NACA

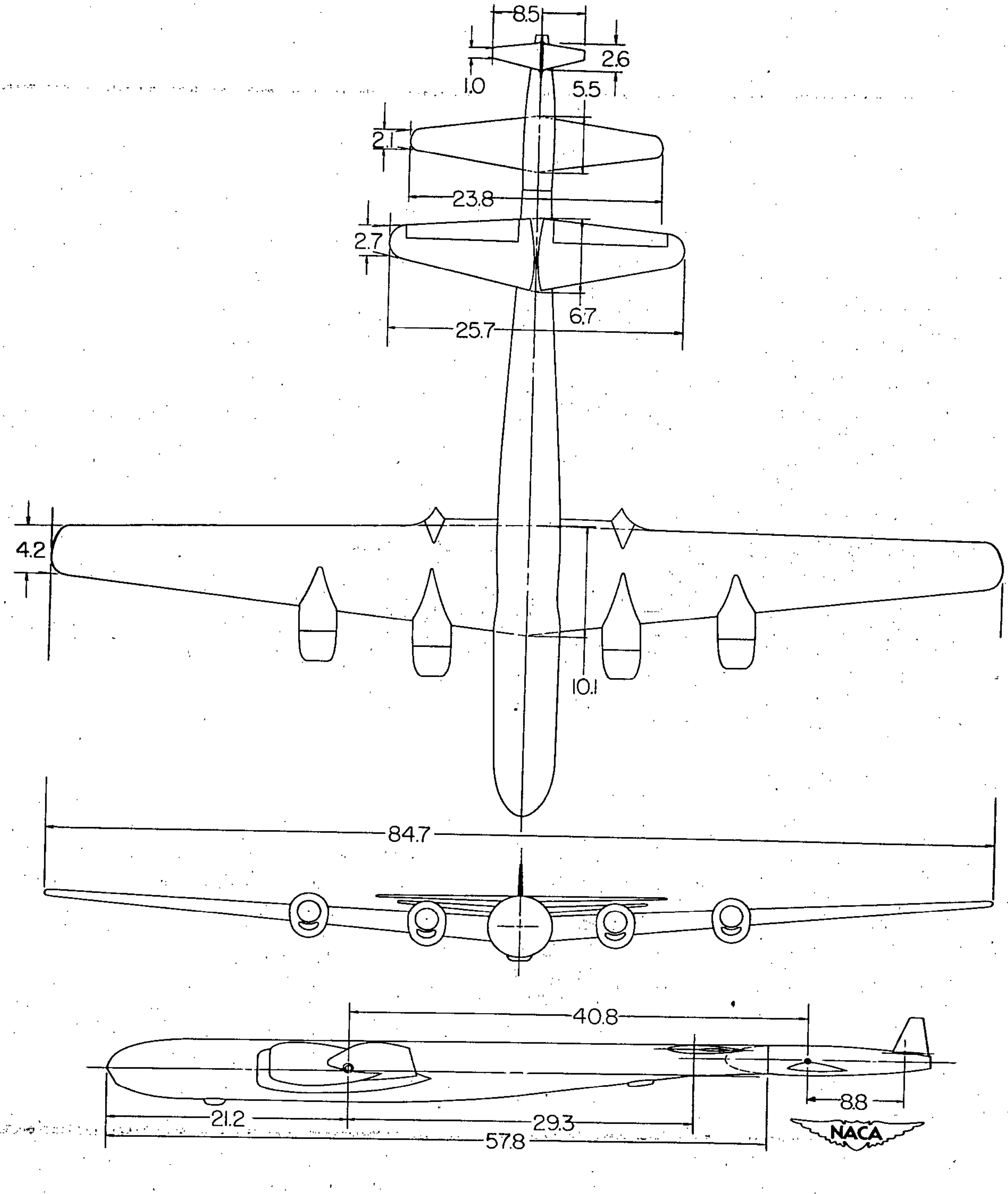

Figure 1.- Three-view drawing of the $\frac{1}{20}$-scale B-29 and F-80 models used for the investigation of the tandem-coupled bomber-fighter airplane configuration proposed by All American Airways, Inc.

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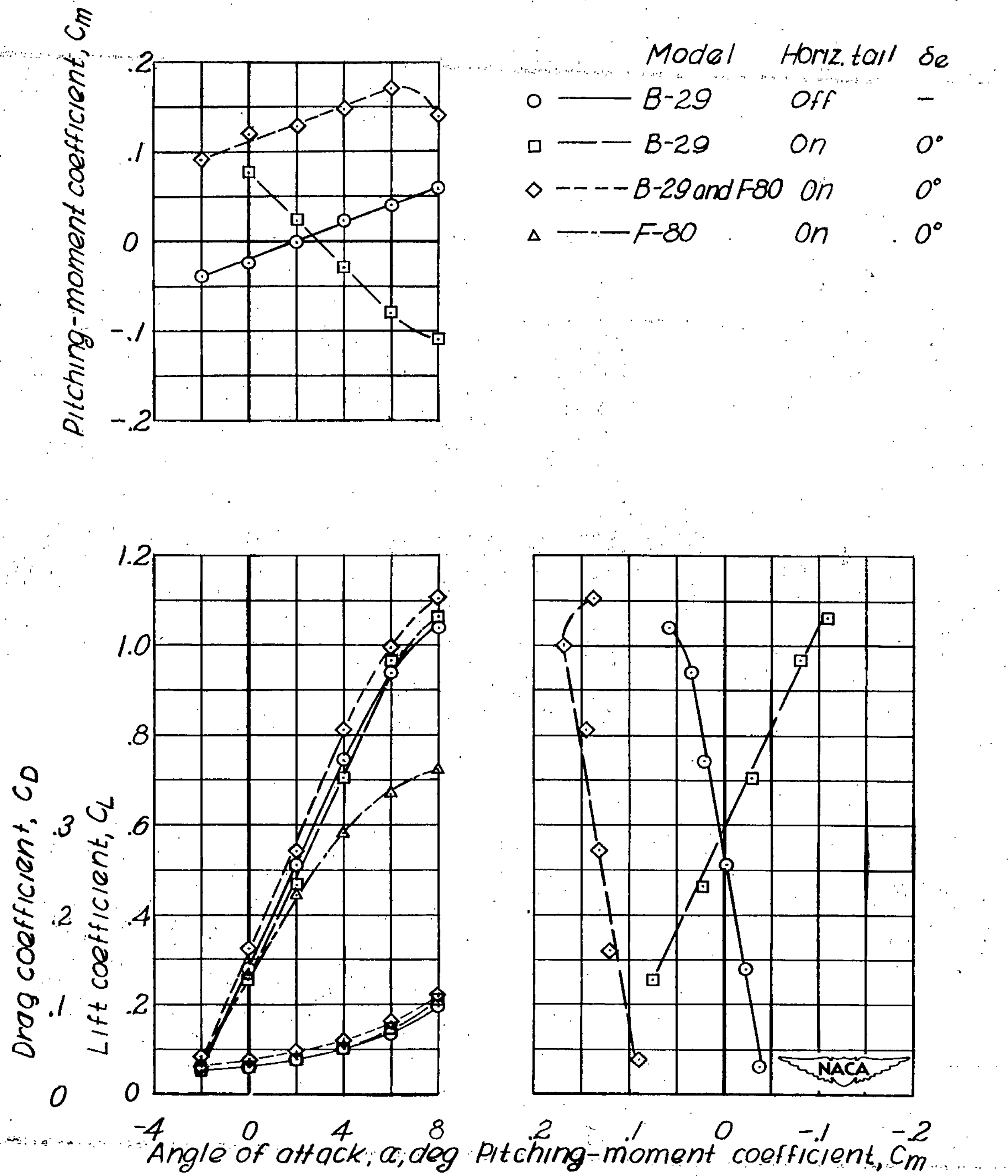

Figure 2.- Force test data for the B-29 and F-80 models alone and for the coupled configuration. $\delta_e = 0^{\circ}$.

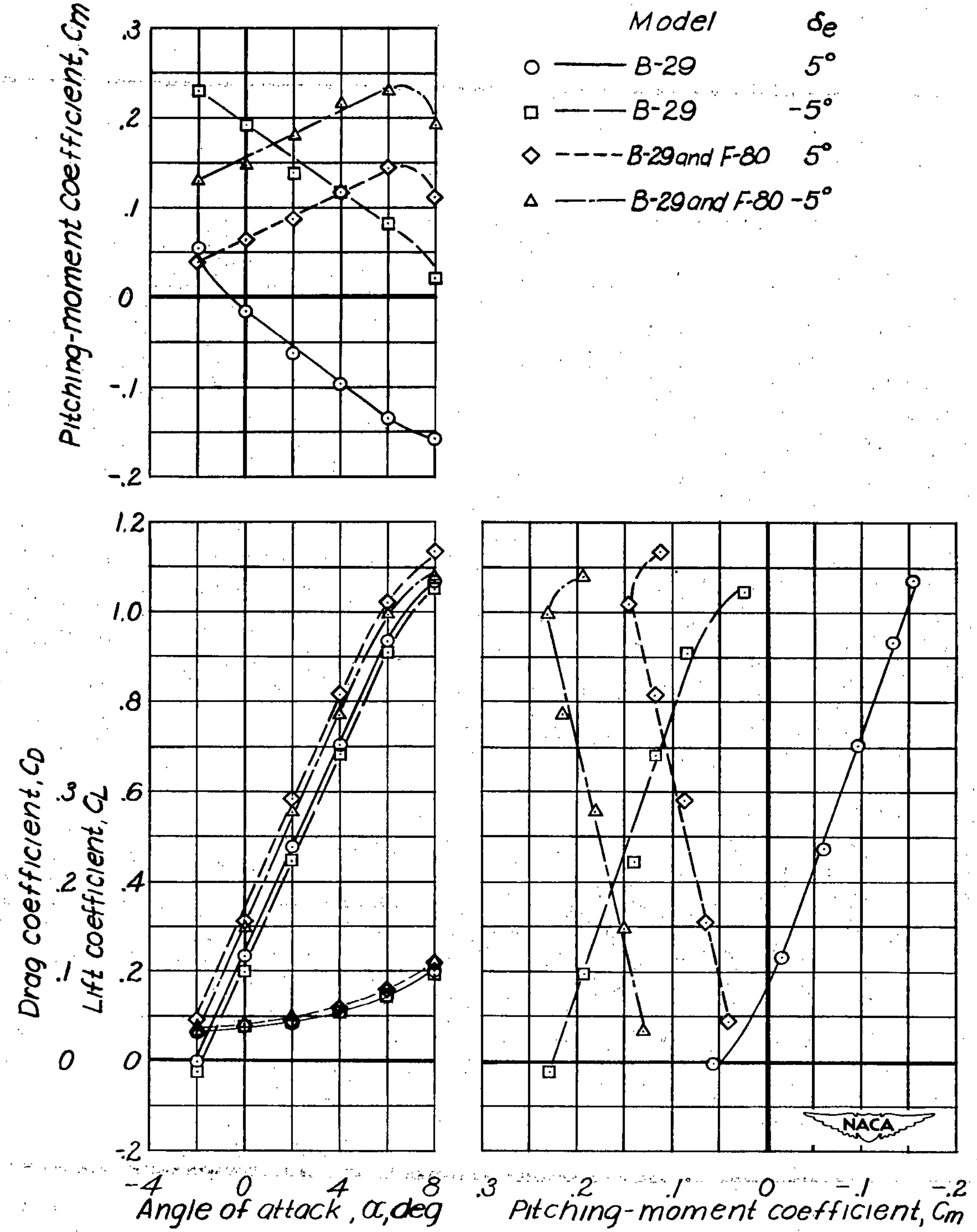

Figure 3.- Force-test data for the B-29 alone and for the coupled configuration with ±5° elevator deflections of the bomber.

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